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Contrasting Conceptions of Intelligence and their Educational Implications

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Technical Report No. 14
November, 1978

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N0001478C0025, Contract Authority Identification Number NR 150-412.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report No. 14	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 Contrasting Conceptions of Intelligence and their Educational Implications.		5. TYPE OF REPORT & PERIOD COVERED Periodic Technical Report 1 Oct 78 - 31 Dec 78
		6. PERFORMING ORG. REPORT NUMBER Research Report No. 14-78
7. AUTHOR(s) 10 Robert J. Sternberg		8. CONTRACT OR GRANT NUMBER(s) N0001478C0025 15 N00014-78-C-0025
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychology Yale University New Haven, Connecticut 06520		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N; RR 042-04; RR 042-04-01; NR 150-412
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research (Code 458) Arlington, Virginia 22217		12. REPORT DATE 11 30 Nov 78
		13. NUMBER OF PAGES 43
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 16 RR04204 17 RR0420401		15. SECURITY CLASS. (of this report) Unclassified 12 56p.
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

intelligence, education, psychometric conception, componential conception

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This article discusses two contrasting conceptions of intelligence--the psychometric one and the componential one--and discusses their differential implications for education. The article opens with a brief historical overview of conceptions of intelligence and their relations to education. Then it discusses the psychometric and componential conceptions of intelligence at some length, placing them within a framework of criteria for theories of intelligence that are claimed to be unbiased and theory-

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free. The article closes with a discussion of the differential implications for education of the two conceptions of intelligence.

Contrasting Conceptions of Intelligence and their Educational Implications

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Contrasting Conceptions of Intelligence and their Educational Implications

Research on intelligence and research on education have proceeded hand in hand ever since the beginning of the twentieth century, although it has never been clear whether this is because of a natural connection between the two or because of an historical accident. The long-standing romance between the two kinds of research (as well as practice) might never have come to be had the Galtonian tradition of research on intelligence become firmly entrenched.

The beginnings of research on intelligence in Sir Francis Galton's laboratory seemed to possess little relevance to the science of education. Galton's anthropometric laboratory, opened in London's South Kensington Museum in 1882, featured measures of strength, sensory acuity, and the like. Galton (1883) conceived of intelligence as something that could be understood in terms of individual differences in sensory types of tasks. Moreover, Galton (1869) believed that intelligence was largely a matter of heredity, and that the best way to increase it was through eugenic measures. To an educator or educational researcher, therefore, Galton's position offered little promise: The tasks used to measure intelligence bore little resemblance to the kinds of tasks pursued in educational settings, and the improvement of intelligenee was to be sought through eugenic rather than euthenic means.

Galton's conception of intelligence was imported to the United States courtesy of James McKeen Cattell (1890), who also bears the distinction of having introduced the term <u>mental test</u> into our vocabulary. Cattell tested students in his laboratory on tasks like those used by Galton, tasks

measuring such skills as sensory acuity of vision and audition, reaction time, sensitivity to pain, color preference, memory, and imagery (see Brody & Brody, 1976). These tasks, like those of Galton, bore little superficial resemblance to the tasks performed in educational settings, and American research revealed that the lack of resemblance was more than skin-deep. Wissler (1901) correlated these tests with each other and with school grades, with disappointing results. The average correlation between pairs of measures was a mere .09, and their average correlation with school grades was a puny .06.

Research on intelligence might have suffered an early and premature death (subject to the kind of reincarnation for which topics of psychological research are famous) were it not for the availability of a contrasting and immediately more fruitful conception of intelligence. As is now well-known, Binet and Simon were asked by the French Minister of Public Instruction to devise a test that would distinguish mentally subnormal children from mentally normal ones. The purpose of such a test would be to segregate the less well-endowed children into classes that would be geared to their particular educational needs. The outcome of this governmental request was the 1905 scale (Binet & Simon, 1905a, 1905b, 1905c), which was followed closely by a revised 1908 scale (Binet & Simon, 1908). The scale for nine-year olds, for example, required the child to know the date on which the testing took place, to recite the days of the week, to make change, to define words, to read a passage and remember certain facts from it, and to arrange five blocks in order of weight. The conception of intelligence operationalized through tasks such as these obviously offered more promise to the educator or educational researcher than did the conception of intelligence operationalized through Galton's tasks: The Binet-Simon tasks were

very much of the type found in school settings, and performance on these tasks could be expected to relate to performance in the classroom. Moreover, Binet, unlike Galton, believed in the improvement of intelligence through euthenic means. Binet proposed a series of "mental orthopedics" intended to improve intelligence through education.

Binet's contribution to intelligence was imported to the United States primarily by Lewis Terman, whose revisions of the Binet scales (Terman & Merrill, 1937, 1960) brought almost instant recognition to the intelligence-testing movement. Whereas Binet originally achieved recognition through his study of the retarded, Terman, like Galton, was interested in the lives of the gifted (Terman, 1925; Terman & Oden, 1947, 1959), and thereby showed the utility of Binet-type tests in distinguishing from the bulk of the population the gifted as well as the retarded. Ironically, the validity of Binet-type tests, like that of Galton-type tests, was called into question by some very early research (Sharp, 1899).[1] But the practical utility of Binet-type tests in educational and other types of settings became established so quickly that the research of Sharp seems to have had relatively little impact.

So the romance between intelligence and education may be traced, in part, to the educational motivation behind the construction of the early Binet-type tests, the view of Binet (and others) that intellectual performance was subject to training, and the continued use of the Binet-type tests in educational settings. Or it may be traced to a natural connection between intelligence and the process of education. But whichever is the case (and both may have played a part), it appears that Binet's conception of intelligence, taken by itself, contained within it the seeds of

discord and ultimately of divorce. The source of this latent problem was the atheoretical nature of Binet's conception. Although this conception might have been sufficient to maintain a bond between intelligence testing in practice and the practice of education, it was not sufficient to maintain a bond between the theory of intelligence (or of intelligence testing) and the theory of education. Fortunately, a third line of research, initiated at about the same time as the research of Binet, salvaged the marriage for a good number of years.

Preceding the publication of the first Binet-Simon scale by just a year was the publication of Charles Spearman's (1904) "'General intelligence,' objectively determined and measured." In this article, Spearman proposed to account for the high degree of correlation between various complex mental ability tests by a general factor of intelligence (g) pervading performance on all of the tests. Support for the existence of this general factor was obtained through the newly developed method of factor analysis, pioneered by Spearman himself. Spearman's theory of intelligence (described in detail in Spearman, 1927) has waxed and waned over the years; but the development of the methodology of factor analysis was a landmark achievement, one sufficient to maintain the marriage of intelligence and education through 50 often troubled years to their golden anniversary and beyond. Factor analysis provided a methodology for the formulation and (weak) testing of theories that provided at least some foundation for the testing of intelligence that was rampant in the schools.

The methodology of factor analysis, and the substantive theories it spawned, endured a number of changes over the years. If Spearman could be said to be the father, then Thurstone could be said to be the rebellious son. Louis L. Thurstone (1938, 1947) may be viewed as having provided the first

major challenge to a theory of the general factor. Others before Thurstone (for example, Thomson, 1939; Thorndike, Bregman, Cobb, & Woodyard, 1926) had challenged Spearman's interpretation and reification of the general factor, but not its status as a factor (or mathematical abstraction). In his theory of primary mental abilities, Thurstone proposed that intelligence is best understood as comprising roughly seven correlated primary mental abilities. The reason that these primary mental abilities failed to appear in Spearman's work is that Spearman left his factorial solutions unrotated, a situation nonideal for optimal interpretation of the factorial nature of intelligence. Thurstone proposed instead that factors be rotated to "simple structure," a structure characterized by factors showing either very high or very low loadings for individual mental ability tests. The debate between Spearman and Thurstone was not easily resoluble, however, because the correlations among Thurstone's primary mental abilities allowed these factors themselves to be factored, and the result of such a factor analysis of factors was usually a general "second-order" factor. There thus seemed to be no clear basis for distinguishing between the two theories via factor-analytic means.

If Thurstone was the rebellious son, Guilford was (at least in some respects) the prodigal grandson, proposing a theory containing no less than 120 factors. These factors could be visualized as forming the volume of a cube, with the three dimensions of the cube representing the operations, contents, and products of mental abilities. Guilford, like Thurstone, rotated his factors. But whereas Thurstone rotated factors to a solution capable of definition independent of the theory being tested, Guilford rotated his factors to maximize fit between the factors and the prior theory

(see Guilford, 1967; Guilford & Hoepfner, 1971). Horn (Horn, 1967; Horn & Knapp, 1973) has discovered some problems with subjective rotation as used by Guilford, and although the merits and demerits of the methodology are not fully resolved, the proliferation of factors spells trouble for those who believe an ultimate goal of science to be the reduction of data.

The problems inhering in Guilford's use of factor analysis in particular and in factor analysis in general (see Sternberg, 1977b, for a discussion of these problems) portended a crisis for the factor-analytic approach to intelligence. Rumblings regarding the fairness of intelligence tests as used in educational settings also became more audible at about the same time, so that by the late 1950's, the marriage between intelligence and education was threatened with dissolution on both theoretical and practical grounds. The two-pronged threat seemed to be a serious one, because the theoretical grounds seemed sufficient for a divorce in the court of science, and the practical grounds seemed sufficient for a divorce in the court of technology. But a paradigm shift was underway in the psychology of cognition, and this paradigm shift was eventually to extend to the study of intelligence.

The year 1960 saw the publication of two extremely influential works proposing an information-processing approach to cognition--Newell, Shaw, and Simon's (1960) "Report on a general problem-solving program," and Miller, Galanter, and Pribram's (1960) Plans and the structure of behavior. In the field of cognition, the paradigm shift to information processing was from behaviorism, not from psychometrics. Factor analysis and related correlational techniques had never exerted much of an impact upon cognitive psychology, although factor-analytic studies of basic cognitive tasks had occasionally been done (for example, Thurstone, 1944). Cognitive psychologists began studying intelligence under other labels, but the connection of their work

to research on intelligence was not explicitly drawn. Some researchers concerned with intelligence saw the potential for the incorporation of the information-processing paradigm into research on intelligence. A largely unheeded Cronbach (1957) proposed an integration between psychometric and experimental research even before the critical year of 1960. Gagné (1967) edited a book containing a series of articles dealing loosely with _Learning and individual differences_ that pointed to some of the ways in which the integration could be achieved. But intelligence researchers were not quite ready for the new paradigm, and the new paradigm was not quite ready for them.

Interest in the information-processing paradigm as a vehicle for studying intelligence took a dramatic upswing in the early 1970's, and the publication of "Individual differences in cognition: A new approach to intelligence" (Hunt, Frost, & Lunneborg, 1973) was the first in a series of events marking this new-found interest. A collection of articles,edited by Lauren Resnick (1976) in a volume entitled _The nature of intelligence_, provided different perspectives on how the information-processing paradigm could be used to study intelligence, and _Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities_ (Sternberg, 1977b) suggested an approach to studying intelligence, componential analysis, that was in some respects a culmination of the initial attempts to merge psychometrics and information processing in the study of intelligence. Although componential analysis draws heavily upon the psychometric tradition, its basic conception of intelligence and of educational interventions is rather different from that of the psychometric tradition.

The remainder of this article will be devoted to a comparison between the psychometric and componential conceptions of intelligence and their relations to education. The discussion will be divided into two major parts. In the

first part, the contrasting conceptions of intelligence will be presented and compared. In the second part, their differential implications for educational theory and practice will be pointed out and discussed. These are obviously not the only two conceptions of intelligence that might be considered. The Piagetian conception of intelligence (Piaget, 1950) has had a substantial impact upon educational theory and practice (see, for example, Athey & Rubadeau, 1970), although its influence upon mainstream intelligence research has been surprisingly small. The restriction in scope of the present article achieves manageability at the cost of completeness.

A Comparison between the Psychometric and Componential Conceptions of Intelligence

Criteria for Comparing Conceptions of Intelligence

In order to compare alternative conceptions of intelligence, one needs a set of dimensions or criteria for comparison that are (a) theory-free, in that they are equally applicable to all theories to be compared, and (b) unbiased, in that they do not put some theories or classes of theories in a more favorable light than others. Such criteria must be, on the one hand, so obvious that no one could question their applicability or inherent reasonableness as bases of comparison, yet, on the other hand, so unobvious that they have eluded past comparisons.

I posed to my research seminar at Yale the question of what criteria would meet these seemingly contrary, if not contradictory, requirements. At the time, I had a set of criteria in mind. It seemed to me that no matter how human intelligence was defined, and why it was defined that way, it had to involve the performance of persons on tasks in certain situations. Persons, tasks, and situations seemed to be the *sine qua non* of a theory of intelligence: No one could be studied in isolation from the others. Hence,

I was ready to propose as criteria (a) a statement of what intelligence is, (b) a justification for this definitional statement, (c) statements of the sources of variation in persons, tasks, and situations, and (d) an account of all possible interactions among persons, tasks, and situations. A graduate student in the seminar, Morty Bernstein, noted that what I was asking for was a "who, what, where, when, why, and how" of intelligence. Bernstein's criteria seem to fill the bill as well or better than my own: These criteria are the essential ones for telling a story, no matter what form the story takes or what content it contains; and indeed, a theory of intelligence (or of anything else) can be viewed as a story of how a particular phenomenon can be understood. Moreover, the criteria are so obvious that they have been used by journalists and story-tellers for innumerable years; yet, they are so unobvious in their application to theories (as stories) that they have been ignored in the comparison of psychological theories of intelligence (and, it appears, of other phenomena as well).

The problem remaining seemed to be that I was left with two sets of criteria, both of them quite plausible, and both seemingly theory-free and unbiased. Which should I use? And how many other sets of criteria lurked in the wings, equally plausible, theory-free, and unbiased? This second question, of course, is unanswerable, but happily, the first question seems to require no answer, because some thought suggests to me that Bernstein's criteria and my own intermap and are interchangeable:

1. "<u>What</u> is intelligence"is equivalent to my criterion requiring a statement of what intelligence is.

2. "<u>Why</u> is that intelligence" is equivalent to my criterion requiring a justification of definition.

3. "<u>Who</u> is intelligent" is equivalent to my criterion requiring a state-

ment of the sources of individual differences among persons.

4. "How is intelligence manifested and thus measured" is equivalent to my criterion requiring a specification of the sources of variation in task performance.

5. "Where and when is intelligence exhibited" is equivalent to my criterion requiring specification of the sources of situational variation.

Interactions among Bernstein's rendition of the criteria may be studied in the same way that interactions among mine would be.

What I find of interest in this anecdotal account is that Bernstein and I arrived independently at two sets of criteria with different surface structures but seemingly identical deep structures. This convergence may suggest some face validity to the deep structure of the criteria as a basis for comparing alternative theories. I will use Bernstein's surface structure in making this comparison.

What is Intelligence?

Three subquestions seem to require answers in addressing the question of what is intelligence. These questions deal with the basic unit or units in terms of which intelligence is to be understood, the structure of intelligence, and the content of intelligence. I will consider each of these questions in turn, first for the psychometric view, and then for the componential view of intelligence.

The psychometric view. Psychometricians seem to agree that the basic unit of analysis in the understanding of intelligence is the factor. As I have noted previously, there has never been much consensus among psychometricians as to just what a factor is. Factors have been viewed as mathematical abstractions representing causes, faculties, parameters, functional

unities, abilities, independent measurements (Thurstone, 1947), as well as determinants and taxonomic categories (Royce, 1963). Cattell (1971) has referred to factors as source traits, and Guilford (1967) has referred to them as underlying, latent variables along which individuals differ. This last definition seems to capture a large part of the meaning that psychometricians have attributed to factors, albeit through different terminologies.

Factors might be viewed as being organized into any of a number of different structural models. Spearman (1904, 1927) originally proposed that a general factor (g) is required for the performance of all tasks involving intelligence, and that a different specific factor (s) is required for the performance of each individual task. There would thus be as many specific factors as there are tasks. Thomson (1939) argued that Spearman's factors could be interpreted in terms of an enormous number of mental "bonds," various combinations of which would be called upon for the performance of different tasks. The general factor could then be understood in terms of those bonds activated in the solution of all tasks under investigation; a specific factor would comprise bonds used only in the solution of a single task. Holzinger (1938) proposed a bi-factor theory, retaining the general and specific factors of Spearman, but permitting group factors as well. These group factors were viewed as common to some tasks but not to others. Spearman, in his later life, came to accept Holzinger's view, and actually collaborated with Holzinger in the further development of the theory. Thurstone (1938) believed that intelligence was best understood in terms of about seven correlated primary mental abilities, and Guilford (1967) extended and elaborated upon a Thurstonian type of model by proposing that there are 120 factors in the structure of

intellect. A view that has been popular in recent years is that proposed by Burt (1940, 1949) and later elaborated by Vernon (1971) and Snow (in press). This view is of a factor hierarchy, with a general factor at the top, successively more narrow group factors at various levels in the middle, and specific factors at the bottom. Humphreys (1962) has recently advocated a similar view, elaborating upon a faceted view of intelligence proposed by Guttman. (See Guttman, 1965, for the best presentation of this view.)

Factor theorists of intelligence have disagreed among themselves regarding the content as well as the structure of mental abilities. In Spearman's view, the general factor applied to task performance regardless of task content, whereas each specific factor applied to the specific content of a given task. Thurstone's seven primary mental abilities were in part content factors: verbal comprehension, verbal fluency, number, spatial visualization, memory, reasoning, perceptual speed. Guilford, recognizing the confounding of content and process in Thurstone's factors, cleanly separated content from process as well as product, yielding factors such as cognition (process) of figural (content) relations (product), convergent production of symbolic units, and the like. The hierarchical models have also differed among themselves as to what elements are inserted at each node of the hierarchy. Burt's (1949) five-level hierarchy contained "the human mind" at the top level; *g* (general ability) and a practical factor at the second, or relations, level; associations at the third level; perception at the fourth level; and sensations at the fifth level. Vernon's (1971) hierarchy put *g* at the top level, verbal-educational (*v:ed*) and spatial-mechanical (*k:m*) abilities at the second level, and successively narrower factors at successively lower levels.

The componential view. In the componential view of intelligence (Stern-

berg, 1977b, 1978, in press[a]), the basic unit of analysis in the understanding of intelligence is the component. A component is an elementary information process that operates upon internal representations of objects or symbols (Newell & Simon, 1972). The process may translate a sensory input into a conceptual representation, transform one conceptual representation into another one, or translate a conceptual representation into a motor output (Sternberg, 1977b).

Understanding of the nature of intelligence requires knowledge of (a) the components that enter into performance on various tasks; (b) the strategies by which different components and multiple executions of the same components are combined; (c) the consistency with which these strategies are executed; and (d) the durations, difficulties, and probabilities of component execution for various components and tasks. Consider, for example, how adults might solve verbal analogies such as LAWYER : CLIENT :: DOCTOR : (1) PATIENT, (2) MEDICINE. According to a recently proposed theory (Sternberg, 1977a, 1977b), six components are involved in solution of this problem: Subjects must (a) <u>encode</u> each of the analogy terms, retrieving from semantic memory the lexical attributes possibly relevant for analogy solution; (b) <u>infer</u> the relation between LAWYER and CLIENT, recognizing that a lawyer provides professional services to a client; (c) <u>map</u> the higher-order relation between the first and second halves of the analogy, recognizing that both halves deal with professionals (LAWYER and DOCTOR); (d) <u>apply</u> from DOCTOR to each of PATIENT and MEDICINE the relation inferred from LAWYER to CLIENT as mapped to DOCTOR; (e) optionally, if neither answer alternative seems ideal, <u>justify</u> one or the other option as preferred but nonideal; and (f) respond. The strategy subjects seem to use in solving analogies of this kind is to (a) encode the attributes of the first two terms; (b) infer as many

relations as possible between them; (c) encode the third term; (d) map one relation from the first half of the analogy to the second; (e) encode the answer options; (f) apply one relation from the third term to each answer option; (g) if the information is sufficient to distinguish a correct option, respond; if not, map and apply other attributes iteratively until sufficient information is obtained to distinguish a correct option and respond; (h) if no solution has been found, justify one option as preferred but nonideal; and (i) respond. Subjects appear to be quite consistent in their use of this strategy (see Sternberg, 1977b). For fairly simple true-false verbal analogies, the durations of the various components were estimated as 1292 msec for encoding of all the terms, 289 msec for inference, 244 msec for mapping, 177 msec for application, and 406 msec for response and other operations constant across analogy types. Since analogies in this experiment were true-false and thus did not involve multiple answer options, justification time was not estimated. An attempt to model component difficulties was unsuccessful for these analogies because of the idiosyncratic knowledge gaps that seemed to lead to errors; attempts to model difficulties of components in which general vocabulary and information did not play a part (schematic-picture and geometric analogies) were successful, however. Finally, no attempt was made to estimate probabilities of component execution, since these probabilities were all assumed to be 1 in this model.

Although the fundamental unit of analysis in the componential view of intelligence is the component, components can be fully understood only in terms of the metacomponents that control them. Metacomponents are the processes by which subjects determine what components, representations, and strategies should be applied to various problems. They determine as

well the rates at which various components are executed, how rate of execution will be traded off for accuracy of execution, and the probabilities that various components are executed at all. Thus, whereas components are involved in the actual solution of problems, metacomponents are involved in the decisions as to how the problems will be solved. Although my collaborators and I have investigated the components of information processing involved in a wide variety of tasks requiring intelligence (see, for example, Sternberg, 1977a, 1978 ; Sternberg, Guyote, & Turner, in press; Sternberg, Tourangeau, & Nigro, in press; Sternberg, Note 1), we have only begun to investigate the metacomponents of information-processing (Sternberg & Salter, Note 2).

Structurally, components may be viewed as organized in much the same way that Holzinger (1938) organized factors. Components are of three kinds. General components (_G_ components) are required for the performance of all tasks within a given universe of tasks. Class components (_C_ components) are required for performance of classes of tasks within the task universe under consideration. Specific components (_S_ components) are required for performance of single specific tasks within the task universe (Sternberg, in press[a]). Of the components considered earlier in the description of the theory of analogical reasoning, encoding and response are general, in that they are required for the solution of all problems requiring intelligence. Inference, mapping, application, and justification are class components, in that they are required for the solution of most inductive reasoning problems (see Sternberg, Note 1) but not for the solution of most deductive reasoning problems. No specific components were illustrated in the theory.

Performance on tasks requiring intelligence may be viewed in terms of the components that in combination constitute this performance. Because

tasks differ in the numbers and kinds of components required, they may be viewed as hierarchically ordered. Thus, the ordering of tasks resembles Burt's, Vernon's, or Snow's ordering of factors. An example of such a hierarchy, for reasoning tasks, is shown in Figure 1. At the top of the

INSERT FIGURE 1 ABOUT HERE

hierarchy one sees general reasoning, which comprises a specifiable set of components (see Sternberg, Note 1, for the currently specified set). Reasoning tasks can be divided roughly into deductive reasoning and inductive reasoning tasks, with tasks of the former kind allowing a logically necessary conclusion and tasks of the latter kind forbidding such a conclusion. Each of these kinds of reasoning involves a specifiable subset of the total set of components. These kinds of reasoning can be subdivided still further, with each subdivision containing components of successively narrower applicability. Note that level in the hierarchy is determined solely by the breadth of applicability of the class components. The general components are applicable to nodes at all levels of the hierarchy, and to each node at a given level; specific components are applicable only to tasks at individual nodes.

Although the organizations of components and tasks bear striking superficial resemblances to the organizations of factors, as noted above, the differences in structural models are probably more basic than the similarities. These differences are in the basic units of analysis, the functional significance of the units, and in the methods by which the units are extracted from sets of data. First, the basic unit of analysis, in the componential view, is a psychological process rather than a hypothetical source of individual differences with only a vague psychological referent. Second,

the function of the component in task performance is readily understood. Performance on tasks can be decomposed into a sequence of components that in combination are sufficient to solve the task. The relations of factors to task performance are less clear. What does it mean, exactly, that different factors have different loadings on various tasks? From a componential point of view, the factors themselves can be understood as comprising various constellations of components that tend to be found together on componentially related tasks. Thus, a general factor comprises general components used in the execution of all tasks within a given task universe; a group factor comprises class components used in the execution of some subset of tasks; and a specific factor comprises specific components used in single tasks. When understood in terms of patterns of individual differences in components, the psychological referents of the factors become more clear. Finally, components are validated and their durations, difficulties, or probabilities of execution estimated via mathematical modeling of differential performance on systematically varied item types (see Sternberg, 1977b), rather than via factor analysis of correlations based on differential performance of randomly selected subjects.

The contents of the components differs markedly from the contents of factors, in that components are processes whereas factors are sources of individual differences of any kind. Examples of component processes, such as encoding, inference, mapping, application, justification, and response, were described earlier in the context of the theory of analogical reasoning. Factors, of course, may refer to types of contents, processes, outcomes, or any combination of these. Componential analysis does not ignore item content and response outcome, however: By varying content and outcome, one learns how each of these affects the processes required for problem solution.

Why is this Intelligence?

The "why" of a conception of intelligence seems to introduce an element of recursion (or circularity, if you prefer) into the set of criteria the conception of intelligence is meant to satisfy. The conception is justified by its satisfaction of a set of criteria, one of which is that the conception of intelligence be justified. Is it possible to break out of this seemingly infinite loop?

The psychometric view. Historically, factor-analytic theories of intelligence seem to have satisfied several generations of psychometric researchers because the factorial model is sufficient to account mathematically for individual differences among subjects in level of intelligence. The traditional inseparability of intelligence and individual differences was underscored by Quinn McNemar (1964), who queried whether even "two supergeniuses, being totally unaware of individual differences, [would] ever hit upon and develop a concept of intelligence" (p. 882). Let us put aside, for the moment, the psychological (as opposed to mathematical) sufficiency of the factorial model in accounting for individual differences, since this issue will be discussed in the next section. Is mathematical sufficiency in accounting for individual differences a sufficient justification for a conception of intelligence?

The componential view. Perhaps because the componential view is most firmly grounded in the information-processing tradition, it deems an account of individual differences necessary but not sufficient for the justification of one or another viewpoint. It further requires an account of intelligence that is sufficient to simulate intelligent behavior: Full understanding of intelligent performance requires, at least in theory, that performance could be mimicked on a computer or other

information-processing device. A complete specification of the components, representations of information, strategies, parameter values, and metacomponents of task solution is sufficient in theory to permit reproduction of the intelligent behavior under study by an information-processing device. I say "in theory" because my colleagues and I have not simulated our information-processing models on a computer, nor do we intend to in the foreseeable future: The necessary ingredients are there, and we have no interest in working out the technical details that would be needed to implement the simulations. We are satisfied that full componential accounts of intelligence are capable of simulation, whereas full psychometric accounts, in themselves, are not.

Although the componential view is grounded primarily in the information-processing tradition, it recognizes and respects the importance of the psychometric tradition as well, and thus must be able to provide a full mathematical account of individual differences among subjects. This account is provided via multiple regression of task scores on information-processing parameters. Each person's score on a task (or factor) is regressed on the information-processing components theorized to contribute to performance on that task (or factor). The better the account the components provide of individual differences in performance, the higher will be the proportion of variance in the task (or factor) scores accounted for by the components.

Who is Intelligent?

The question of who is intelligent requires a specification of the psychological sources of individual differences. What forms do these accounts take in each of the two views of intelligence under consideration?

The psychometric view. In the psychometric view, each person may be

characterized in terms of a series of scores on each of the factors constituting intelligence. These factor scores are expressed in standard-score units, and indicate the relative amounts of each ability that a given subject possesses. But what, exactly, does a standard score of -1 or 1 on a "reasoning" factor mean psychologically (as opposed to mathematically, or even normatively)? Does this score explain why one subject is less intelligent, or less adept at reasoning, than another, or is it a restatement of this fact itself in need of explanation?

The componential view. The componential view, unsurprisingly, is that individual differences in factor scores are interesting data that themselves need to be explained. The sources of individual differences in componential analysis are in the aspects of performance that make it "intelligent":

1. Subjects differ in the components they apply to tasks, either because of differential availability or because of differential accessibility of various components, and failure to apply task-relevant components or failure in applying task-irrelevant components is indicative of less intelligent performance. For example, in the solution of analogy problems having as content a particular kind of schematic picture, second-graders do not map from the first half of the analogy to the second, whereas fourth-graders, sixth graders, and adults do map (Sternberg & Rifkin, in press). This difference in component utilization is proposed to reflect a difference in level of intelligence. Note, though, that the qualitative specification of the nature of the difference is much more informative than a simple description of the second graders as "less intelli[illegible]" quantitatively than the older subjects.

2. Subjects differ in their re[illegible]entations of information and in the flexibility with which they apply th[illegible]e representations. Consider, for example,

various kinds of induction problems that can be formed from the set of mammal names. In an analogy, a subject might be asked to solve a problem like RAT : PIG :: GOAT : (1) CHIMPANZEE, (2) COW, (3) RABBIT, (4) SHEEP. Problems like these were originally used in a study of analogical reasoning conducted by Rumelhart and Abrahamson (1973). Another type of item is the classification, in which a subject is asked which of four answer options best fits with three terms in the item stem, for example, MOUSE, CHIMPANZEE, CHIPMUNK, (1) GORILLA, (2) RAT, (3) SQUIRREL, (4) ZEBRA. In a third type of item, the series completion, subjects are asked to choose the term that best completes a brief series: RABBIT : DEER : (1) ANTELOPE, (2) BEAVER, (3) TIGER, (4) ZEBRA. In studying the animal-name analogies, Rumelhart and Abrahamson proposed that subjects represent the relations among terms in a multidimensional semantic space containing dimensions such as size, ferocity, and humanness. In our own investigations (Sternberg, 1977b; Sternberg & Gardner, Note 3), we have found evidence that subjects may also use an overlapping clustering representation, grouping together overlapping classes of animals such as jungle animals, felines, domesticated pets, etc. Each of these kinds of representation can be useful in converging upon the best of the presented solutions to a given reasoning problem. We would propose, therefore, that more intelligent subjects are more able and willing to consider a number of possible representations for information, choosing the one or more representations that are most useful for the solution of a particular problem.

3. Subjects differ in their strategies for combining different components and multiple executions of the same components, and certain strategies come closer to optimizing performance than do others; use of more nearly optimal strategies is indicative of more intelligent performance. For example,

in solving analogy problems, children's strategies become more nearly exhaustive with age (Sternberg & Rifkin, in press). In concrete terms, this means that older children consider more of the attributes relating pairs of terms in an analogy before selecting an answer option. This particular example of increasingly exhaustive information processing over age appears to be indicative of a strategy change that is evident over a wide range of problems (see Brown & DeLoache, 1978). In what sense does more nearly exhaustive processing come closer to optimizing some criterion in task performance than does less exhaustive processing? It has been found previously (Sternberg, 1977b) that errors in analogical reasoning with schematic and geometric pictures are due almost exclusively to early termination in attribute comparison. Processes that are executed exhaustively seem rarely to lead to errors. Thus, the steep decline in error rates for analogical reasoning with increasing age (Sternberg & Rifkin, in press) are probably due in large part to the increased use of exhaustive processing by older children. Again, the qualitative specification of the nature of the difference is more informative than a simple specification of a quantitative difference in level of performance.

4. Subjects differ in the consistency with which they employ various strategies, and these differences can be indicative of differential levels of intelligence. Consistency is a two-edged sword. On the one hand, consistency can be the sure sign of a dull mind. Luchins (1942) showed in his studies of mechanization in problem solving that the establishment of a strong set for problem solving can prevent one from seeing creative short-cuts to problem solution. On the other hand, inability to settle upon a consistent strategy in problems requiring a minimum of strategy change can result in time wasted due to the lack of an efficient system of problem solving. Bloom and

Broder (1950), for example, found that poorer reasoners were inconsistent in their responses to problems, and tended to muddle through rather than settling upon a consistent approach to problem solving. We have found in our own research (Sternberg, 1977a, 1977b; Sternberg & Rifkin, in press) that better reasoners tend to be characterized by more consistent and systematic approaches to solving reasoning problems.

5. Subjects differ in component values, and these differences are indicative of differential intellectual ability. Straightforward, quantitative comparisons of psychometric parameters have been the mainstay of the psychometric approach, in which it has generally been assumed that higher accuracy scores or lower speed scores are associated with greater intelligence. Interestingly, the relationship between parametric values and intelligence is not as straightforward as it may appear. In general, we have found that faster performance on a large variety of information-processing components on an assortment of different tasks is indeed associated with higher intelligence (Sternberg, 1977a, 1977b; Sternberg & Rifkin, in press; Guyote & Sternberg, Note 4; Sternberg, Note 5). However, in at least one case, faster component execution appears to be associated with lower intelligence (Sternberg, 1977a, 1977b; Sternberg & Rifkin, in press). In reasoning by analogy, slower encoding of analogy terms appears to be preferable to faster encoding because it permits subsequent comparisons upon these encodings to be performed more efficiently. Presumably, sloppy encodings near the beginning of problem solving impede the operations upon these encodings that need to occur later on. This result indicates that one cannot automatically assume that faster information processing is better. Faster overall information processing may be obtained by slowing down one component in order to speed up others.

6. Subjects differ in the metacomponential decisions they apply to their information processing, and these decisions can be indicative of individual differences in intelligence. An example of such a decision was noted above. The decision to slow down encoding in order to facilitate subsequent operations is apparently a wise one that results in an overall increase in processing efficiency.

To summarize, the sources of individual differences in the componential view of intelligence are qualitative as well as quantitative, and express how differences across subjects in intelligence can be understood in terms of differences in aspects of information processing. These differences in information processing seem more revealing of the nature of individual differences in intelligence than do differences in scores on one or more psychometric factors.

How is Intelligence Manifested and thus Measured?

The "how" of intelligence requires a theory of tasks. What is it that distinguishes one task from another, and that makes some tasks better than others as measures of intelligence?

The psychometric view. According to this view, tasks differ in their loadings on various factors: A task is a good measure of *g* to the extent that it shows a high loading on the general factor; a task is a good measure of spatial ability to the extent that it loads highly on a factor of spatial visualization. Performance on a task can be characterized in terms of its loadings on the various factors constituting intelligence according to a particular theory. This view of differences among tasks presents roughly the same problem as did the view of differences among subjects. In this case, what does it mean for a task to load highly on a factor? In what sense does a pattern of factor loadings "explain" performance on a task, and in

what sense does this pattern constitute a set of data itself in need of explanation?

The componential view. The componential view of tasks is that tasks differ in the (a) components and metacomponents they require, (b) contents and formats upon which the components and metacomponents operate, and (c) strategies they allow for combination of components. The psychologist chooses tasks that require the components theorized to be important in a given theory of intelligence. These would tend to be general components and class components of relatively wide generality, such as the components of analogical reasoning described earlier. Loadings of tasks on factors are understood in terms of the components shared between tasks and factors. For example, inference is a class component that is likely to contribute as a source of individual differences to a general reasoning factor, and it is also likely to be required for the performance of a variety of reasoning tasks. A task requiring inference will thus attain some of its loading for "general reasoning" from the inference component. The more components the task shares with the factor, and the more these components contribute to individual differences in task performance, the higher the factor loading for the task will be.

"Where" and "When" is Intelligence Exhibited?

The "where" and "when" of intelligence require a theory of situations, but such a theory is strangely absent from psychometric and componential theories alike. It has generally been assumed that tasks should be administered under conditions that minimize distraction--ample but not excessive lighting, quiet, reasonable but not excessive comfort, and so on. It is apparent, however, that in the real world, task performance rarely occurs under anything even approaching ideal conditions. I write this and other

articles at home rather than at my office in order to minimize distractions. Yet, even as I write today, the phone rings intermittently, the painters painting the interior of our house ask me questions, a light bulb burns out, the lure of snacks (and, more legitimately, meals) entices me away from my desk, and on the list goes. Intelligence does not exist in a vacuum, and yet we have often studied it as though it does. There has been some research in the psychometric literature, of course, on how various environments affect measured intelligence, and some research in the information-processing literature on how various distractions disrupt performance. Using componential analysis, one could determine quite precisely just what aspects of task performance are affected by what distractions. But what is missing is a rational account of the situations under which intelligence _should_ be studied, as opposed merely to an account of the situations under which it _could_ be (and has been) studied. Until we have a theory of situations, our theoretical accounts of intelligence will be incomplete.

Educational Implications of the Psychometric and Componential Conceptions of Human Intelligence

The Psychometric Conception

The psychometric conception of intelligence seems never to have held much promise for education. The kind of question addressed was capsulized by the title of Jensen's (1969) article, "How much can we boost IQ and scholastic achievement?" Given that IQ is the principal indicator of intelligence in the psychometric approach, it has been natural to view the interface between research on intelligence and research on education as research devoted to the creation, implementation, and testing of techniques to boost IQ. Unfortunately, the psychometric conception of intelligence in itself gives no clues as to the ingredients that should go into

the booster shot. The blank prescription for training is inherent in the nature of psychometric theories: They are static quantitative accounts of individual differences among subjects and differential relations among tasks. As such, they are inadequate in four respects.

First, psychometric accounts of intelligence are static, failing to elucidate the dynamic information processing that is behind whatever it is that IQ measures. An account of intelligence that is silent with respect to information processing cannot be expected to suggest how this information processing can be modified in ways that will increase its power, efficiency, or overall quality.

Second, the accounts are quantitative, describing differences in "amounts" of one or more hypothetical abilities attributed to subjects. But being told the amount or amounts of assets in one's mental bank account or accounts does nothing to tell one how to increase the assets. Even the psychometric bank statements that provide breakdowns of assets present an array of quantities without adequate descriptions of the qualities measured by each of these quantities.

Third, psychometric accounts are normative, describing one individual's assets relative to those of other individuals. Knowing how one's assets compare to another's does nothing to show how those assets can be increased, either with respect to one's other assets or with respect to the other's assets.

Fourth, psychometric accounts are of differential relations among tasks: The nature of a task is defined by its correlational and factorial relations to others tasks, just as an individual is defined in terms of his or her relations to other individuals. But understanding of a task requires knowledge of the task's internal composition as well as knowledge

of the task's external relations to other tasks.

The earliest psychometric tests of intelligence provided single indices of intelligence, such as IQ (for example, the Stanford-Binet scale presented by Terman & Merrill, 1937). Such single indices were of little diagnostic value, and contained no implications for training intelligence. Later tests often provided two or more indices, such as a verbal and performance score (Wechsler, 1958) or a series of primary mental ability scores (Thurstone, 1938). But such multiple scores were just as static as the single score: Spatial ability, say, was defined in terms of its test loadings rather than in terms of the processes that constitute it. Although multiple scores possess more potential diagnostic value than single scores (but see McNemar, 1964), they possess no more clues regarding how intelligence can be trained.

Realizing the sterility of the psychometric conception of intelligence as a basis for training intelligence, many psychometricians turned to the study of aptitude-treatment interactions, finally following the lead that Cronbach (1957) suggested could result in the merger of the two disciplines of scientific psychology. A major goal of this research has been to discover what kinds of instructional treatments are most suited to various patterns of aptitudes. This research could have become a means to bypass the training issue entirely: Rather than modifying aptitudes to suit instruction, one could be content to modify instruction to suit existing aptitudes. Many aptitude-treatment theorists, however, have been interested in modifying aptitudes as well as adapting instruction. But much of the aptitude-treatment interaction research has been disappointing in its outcomes (see Cronbach & Snow, 1976). There are any number of statistical reasons for the disappointing outcomes, as noted by Cronbach and Snow in dazzling detail. But my reading of this literature is that many of the disappointments were

attributable as much to conceptual inadequacies as to statistical ones. Most of the research was motivated by static psychometric conceptions of intelligence that just were not likely to lead to an understanding of how aptitude processes interact with instructional ones; moreover, existing information-processing accounts available when most of the research was done were inadequate. More recent research, based upon more adequate conceptualizations of information processing, seems likely to hold more promise (see Snow, in press, Note 6).

The Componential Conception

The componential conception of intelligence, unlike the psychometric one, contains within it direct implications for the modification of intelligence. Consider what the modification of intelligence or intelligent performance means from a componential point of view. In order to make this consideration more concrete, I will use as an illustration of intelligent performance, performance on a single task, the linear syllogism. In a linear syllogism, a subject is presented with a pair of premises, such as "John is not is tall as Pete; Pete is not as tall as Bill," and must answer a question based upon these premises, such as "Who is tallest?"

First, one needs to know the information-processing components that are both available and accessible for task performance. Inadequate performance on a task (however defined) may be attributable to unavailability of the components necessary for adequate performance, or to their inaccessibility. In the latter case, the components are available to the subject, but for one reason or another, are not accessed when needed for solution of a particular problem. Lacking certain components needed for solution of a problem by a particular strategy, the problem-solver may (a) attempt to solve the problem using that strategy but omitting the unavailable or

inaccessible components, (b) attempt to use that strategy, substituting other components for the unavailable or inaccessible ones, or (c) change to a different strategy that does not require the unavailable or inaccessible components. Consider the linear syllogism. The large majority of adults use a strategy for solution requiring as many as twelve information-processing components (Sternberg, Note 5). Among these components is that of negation. It has been found, however, that children as old as seven or even eight years of age have considerable difficulty in processing negations (see Sternberg, Note 7). Hence, many of these children would be obliged to solve linear syllogisms containing negations in a way that somehow bypasses the negation component. Because negation seems to be a mandatory component in the solution of these problems, such a way of solving the problems would be likely to lead to a high error rate. Components can be trained, however, at least in some cases. A group of adults was trained to use a strategy for solving linear syllogisms that was largely nonoverlapping in the components it required with the components required by the strategy routinely used by untrained adults solving these problems (Sternberg & Weil, Note 8). Not only were the adults able to use these different components after an initial period of adjustment--their performance on the linear syllogisms became much more rapid and efficient.

Second, one needs to know the representations upon which these components act. I emphasize the use of the plural here, because I suspect that a great deal of futile debate in psychological theory has gone into attempting to decide which one of several forms of representation subjects use, when in fact the subjects are as able to use multiple representations as the psychologists studying the subjects. For example, the literature on linear syllogisms has consisted in large part of attempts to resolve

a debate over whether subjects use a spatial or linguistic representation for information (see, for example, Clark, 1969; DeSoto, London, & Handel, 1965; Huttenlocher, 1968; Johnson-Laird, 1972). It now appears that subjects, like experimenters, are able to use both linguistic and spatial representations for information (Sternberg, Note 5), employing them at different points in the solution process. Indeed, their flexibility in utilizing both forms of representation is a hallmark of their intelligence. If subjects are unaware of the correct form of representation, they often can be trained to use it, as we did in training one group of subjects to represent linear arrays spatially (Sternberg & Weil, Note 8). If subjects have the ability to use a certain kind of representation, then they should have no trouble utilizing it upon demand. Where alternative representations can be used to solve problems, subjects can be trained to use that form of representation that best capitalizes upon their patterns of abilities. For example, low spatial subjects might be trained to solve linear syllogisms using an exclusively linguistic representation for ordering relations, whereas low verbal subjects might be trained to use an exclusively spatial representation for these relations.

Third, one can intervene in the strategy or strategies by which subjects combine components, as we did in the linear-syllogisms training study cited above. In this particular case, the new strategy required components largely different from those subjects normally use. It is also possible, however, to train subjects to use the same components according to alternative strategies, as we are now doing in the solution of analogy problems (Sternberg & Ketron, Note 9). Such training can be important in cases where subjects use the right components, but combine them in the wrong ways.

The remaining kinds of training implied by the componential conception of intelligence are metacomponential in nature. A fourth kind of training is in the attainment of just the right amount of flexibility in problem-solving strategy. What makes this training "metacomponential" is its involvement of decisions about how to solve a problem, rather than of the actual acts that result in the solution of the problem. Thus, training a subject how to settle upon a strategy is metacomponential training, whereas training the subject to use a particular strategy is not. Some subjects have trouble settling upon a strategy and sticking with it--they seem to flounder endlessly. Other subjects are unwilling initially to spend the time needed to find the optimum strategy--they settle upon the first minimally satisfactory strategy they can find, and then stick with it (Simon, 1957).

Fifth, one can train subjects to modify their rate or accuracy of component execution. What makes this kind of training metacomponential is that it almost inevitably involves a decision regarding speed-accuracy tradeoff in problem solution. One can rarely modify rate of component execution without modifying accuracy of component execution, and vice versa. For example, in a study of linear-syllogistic reasoning (Sternberg, in press[b]), the subjects were instructed to emphasize speed in solving problems. Accuracy, of course, was impaired. As often happens when accuracy is sacrificed for speed, small gains in speed can result in substantial decrements in accuracy. In this particular experiment, a 30% increase in speed resulted in a 700% increase in errors.

Other kinds of metacomponential training are possible, at least in theory. Subjects can be trained to avoid representations with which they are uncomfortable, to avoid strategies that make excessive working-memory

demands, to use strategies that apply to an entire class of problems rather than just to individual problems within a class, etc. But as psychologists and educators, we know so little about metacomponential information processing, that in practice, our ability to instruct individuals in how to make decisions at the metacomponential level is severely restricted. This restriction seems to derive from the insufficiency in our knowledge about the components and metacomponents of intelligence, rather than from the insufficiency of the componential conception of intelligence. Indeed, the componential conception of intelligence seems capable of making us aware of just what kinds of further information we need in order to improve our training procedures. And if a conception of intelligence leads us to ask the right questions, as well as leading us to some tentative answers, then the conception seems to hold promise for the future as well as the present. The superiority of the componential conception over the psychometric conception as a basis for training seems to derive from the former's being dynamic rather than static, qualitative rather than quantitative in nature, concerned with the mechanisms of individual performance as well as with description of individual differences in performance, and capable of analyzing the internal structure of individual tasks as well as the external relations among multiple tasks. These qualities translate themselves into prescriptions for the kinds of ingredients that can go into a "booster shot" for maximizing people's potentials for intelligent behavior.

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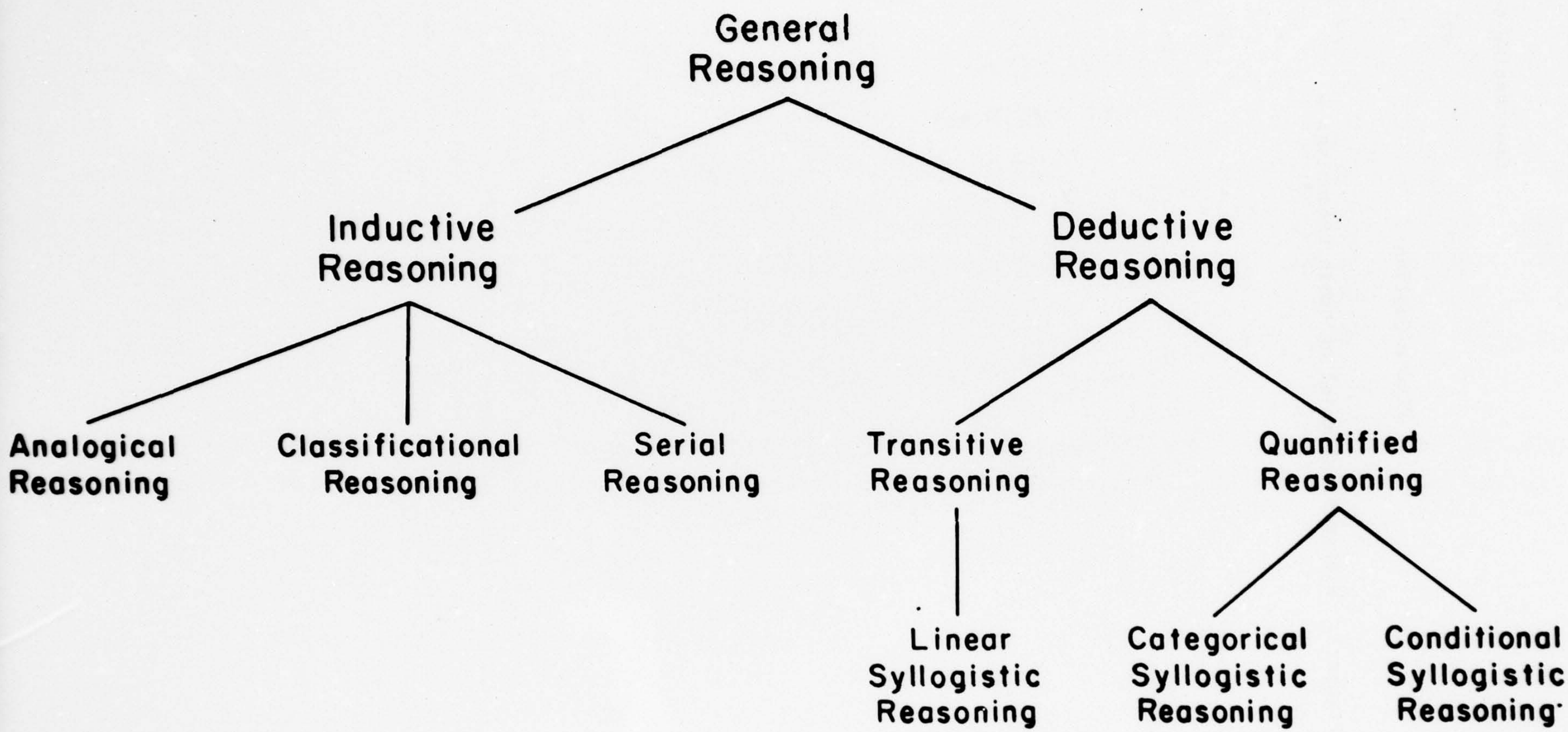
Footnotes

Preparation of this article was supported by Contract N0001478C0025 from the Office of Naval Research to Robert J. Sternberg. I am grateful to the members of my research seminar at Yale, and particularly to Morty Bernstein, for helpful suggestions that have improved the quality of the report. Requests for reprints should be sent to Robert J. Sternberg, Department of Psychology, Yale University, Box 11A Yale Station, New Haven, Connecticut 06520.

[1] Sharp's research appears to have been rather seriously flawed, in that it was based upon a very small number of cases (seven), suffered from severe restriction of range in sampling variation (subjects were graduate students at Cornell), and utilized individual tests of low reliability.

Figure Caption

Figure 1. Hierarchical model of human reasoning.


General Reasoning
Inductive Reasoning
Deductive Reasoning
Analogical Reasoning
Classificational Reasoning
Serial Reasoning
Transitive Reasoning
Quantified Reasoning
Linear Syllogistic Reasoning
Categorical Syllogistic Reasoning
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